final technical report

SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS

volume II - book 2
part III — communication system

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final technical report

SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS

volume II - book 2

part III — communication system

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Bethpage, New York 11714

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FINAL REPORT

NASA SPACE STATION

RF COMMUNICATIONS AND TRACKING SUBSYSTEM ARCHITECTURE STUDY

FEBRUARY 1983

Prepared for:

Grumman Aerospace Corporation
Bethpage, N.Y. 11714

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FINAL REPORT

NASA SPACE STATION

RF COMMUNICATIONS AND TRACKING SUBSYSTEM

ARCHITECTURE STUDY

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NASA SPACE STATION

RF COMMUNICATIONS AND TRACKING SUBSYSTEM ARCHITECTURE STUDY

1. INTRODUCTION AND OBJECTIVES OF STUDY

This report summarizes the preliminary results of the study of the architecture and attributes of the RF communications and tracking subsystem of the space station (S/S). The study is limited to communications between the space station and other external elements such as TDRSS satellites, low-orbit spacecraft, OTV, MOTV, in the general environment of the space station. Figure 1.1 shows many of the space environment factors which will affect the RF communications of the space station interface.

The overall objectives of the study are to:

- Define and analyze the RF communications subsystem attributes and characteristics (external communications for the initial space station (1990)).
- Identify key issues for evolution from an initial space station (1990) to a year 2000 space station.
- Examine mass and power characteristics of the communications subsystem for the initial space station.

- Identify impact of advanced technology developments.
- Identify changes needed to the second-generation TDRSS to accommodate the evolutionary space station of the year 2000.

The emphasis of the study is placed on the initial (1990) space station RF Communications and Tracking subsystem (RFCT) which has more modest requirements than the fully operational year 2000 space station. This provides the advantage of allowing a fairly realistic assessment of feasibility of mass and power requirements since the available technology is not expected to be substantially more advanced than those of 1983-1986. From this vantage point it is possible to make somewhat more reasonable projections of capability, feasibility, and requirements for the fully operational space station projected for year 2000.

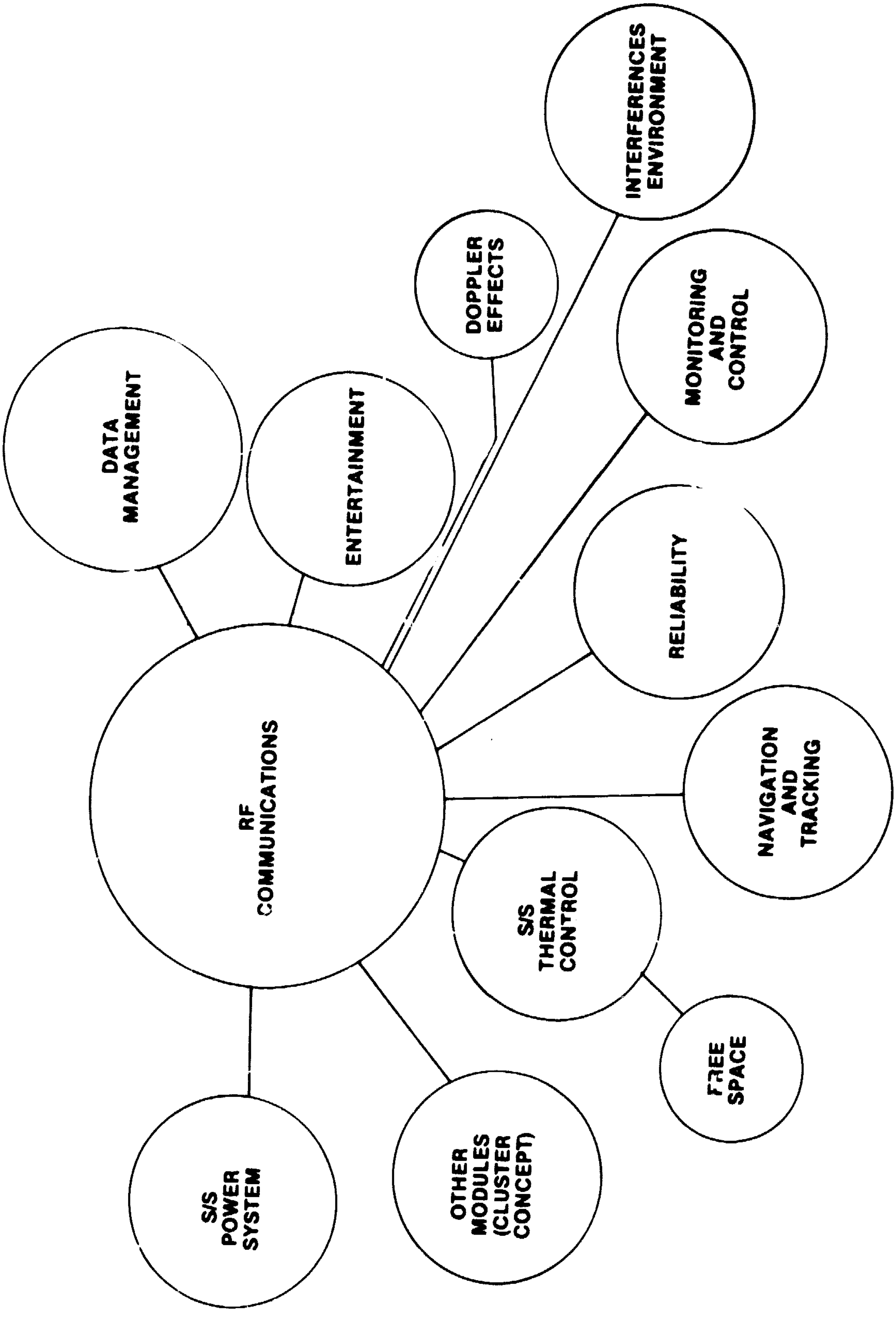

Figure 1.1 Space Environment

2. NASA/GRUMMAN GENERAL REQUIREMENTS FOR SPACE STATION

General requirements supplied by Grumman Aerospace Corporation or defined by NASA for the year 2000 space station communications and tracking subsystems are highlighted in Table 2.1. Figure 2.1 shows the antenna coverage requirements and Table 2.2 lists the aggregate data rate and data traffic requirements for the on-board Data Management System of the space station. The overall communications environment is pictured in Figure 2.2.

From these requirements, a more modest set is selected for the initial space station (year 1990).

TABLE 2.1.A

NASA/GRUMMAN GENERAL REQUIREMENTS FOR THE INITIAL AND FULLY OPERATIONAL SPACE STATION RF COMMUNICATIONS AND TRACKING SUBSYSTEM

Time Frame	1990 - 2000 Initial station launched: 1990 Secure communications operational: 1995 Fully operational: 2000
Functions	RF external communications services (voice, video, data). Navigation and tracking service. External communications: Orbiter, EVA crewmen, Freeflyer, OTV, MOTV, remote teleoperator maneuvering system, co-orbiting satellites, military satellites.
Systems Operational Elements	Space station on-board modules: space station subsystems, laboratories, habitat units, satellite servicing units, test range units, transportation harbor, assembly/manufacture unit.
Space Station Configuration Alternatives	Alternative 1 - Single vehicle made of integrated modules. Alternative 2 - Cluster of modules interconnected by RF links

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Note: Radar traffic control system not included in CGC study.

TABLE 2.1.A (cont.)

Links	1) Communications (non-military). - Space station and external users. - Space station and ground facilities via TDRSS/TDAS. - Space station and GSTDN via direct link. - EVA activities on the space station. 2) Navigation/Tracking - Global Positioning System (GPS) - TDRSS tracking services (can be used as back-up if desired).* 3) RF links between S/S modules (inter-module links)** (this applies to the cluster concept). 4) Military communications**
Orbital Parameters	1) Altitude/inclination: 230 n.mi./28.5° (initial system) Other candidates: 200 n.mi./90°; 215 n.mi./60° 2) Orbital period: about 90 minutes

---

* Assumed by CGC.
** Not part of CGC Study.

TABLE 2.1.A (cont.)

Some Typical Design Characteristics of Space Station

1) Field of view: See chart of Figure 2.1

2) Prime power for communications and tracking subsystem: 2 KW (design goal)

3) Attitude = ±2°

4) Navigation - GPS; star tracker

5) Interference environment: ground-space
space-ground
space-space
intentional/accidental

TABLE 2.1.B

FULLY OPERATIONAL SPACE STATION RF COMMUNICATIONS LINKS

	No. of Vehicles to be Serviced Simultaneously	Frequency Band
Relay satellite	1	S, Ku, (mm, Laser)
Orbiter	2	S
EVA	4	UHF
MOTV	2	Ku (mm, Laser)
OTV (un-manned)	2	Ku (mm, Laser
Free-Flyer	4	S, Ku, (mm, Laser)
GPS	1	L
	16	

Note: Tracking radar is not included in the CGC Study.

TABLE 2.1.C

PRELIMINARY DATA CHARACTERISTICS OF SPACE STATION

1)	Aggregate Return Data Rate: (S/S to Ground via Relay)	Initial System 300 Mbps (Ku-band (KSA))* 3.15 Mbps (S-band (SSA))* 500 Mbps for fully operational system
2)	Forward Data Rate from Ground: (Ground to S/S via Relay)	Initial System 20 Mbps (Ku) 300 Kbps (S-band) Based on maximum TDRS capability
3)	Daily Data Volume Estimated:	Up to 10^{13} bits/day (initial) Up to 2×10^{13} bits/day (fully operational)

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* KSA = K-band single access.
  SSA = S-band single access.

TABLE 2.1.D

SOME OPERATIONAL CHARACTERISTICS OF SPACE STATION

Space Station Quiescent State

- Quiescent state (powered down) operations required (space station in a stand-by un-manned mode).
- Ground command via relay satellite will operate the necessary space station equipment required to maintain minimum communications and monitoring the status of equipment.
- Activation/de-activation by ground commands during quiescent state to provide status monitoring and operational readiness prior to manning of space station.

Timing

All timing shall be derived from a clock on-board the space station.

Reliability

Fail operational/fail safe.

TABLE 2.1.D (cont.)

Operational Characteristics

Interruptibility

Some interruptibility due to orbital geometry constraints, space station/spacecraft configuration antenna blockage is acceptable except for EVA communications.

- Simultaneous Link Operation

All links from/to the space station should be able to operate simultaneously up to one TDRS, two orbiters, four EVA, two OTV, two MOTV, four free-flyers, one GPS links. The practicality of this requirement is to be evaluated.

TABLE 2.1.D (cont.)

Monitoring and Control Philosophy

- Automatic status and fault monitoring (to be monitored by the on-board space station control center and by the ground control center).
- Computerized diagnostic capability to the maximum extent possible.
- Automatic switchover of redundant units.
- Manual override of switchover function either from on-board control center or ground control center (via command link).
- Remote testing for diagnostic verification and other purposes from on-board control center or from the ground via command link.
- Autonomy - space station operated (manned) with a high degree of independence with ground control override.

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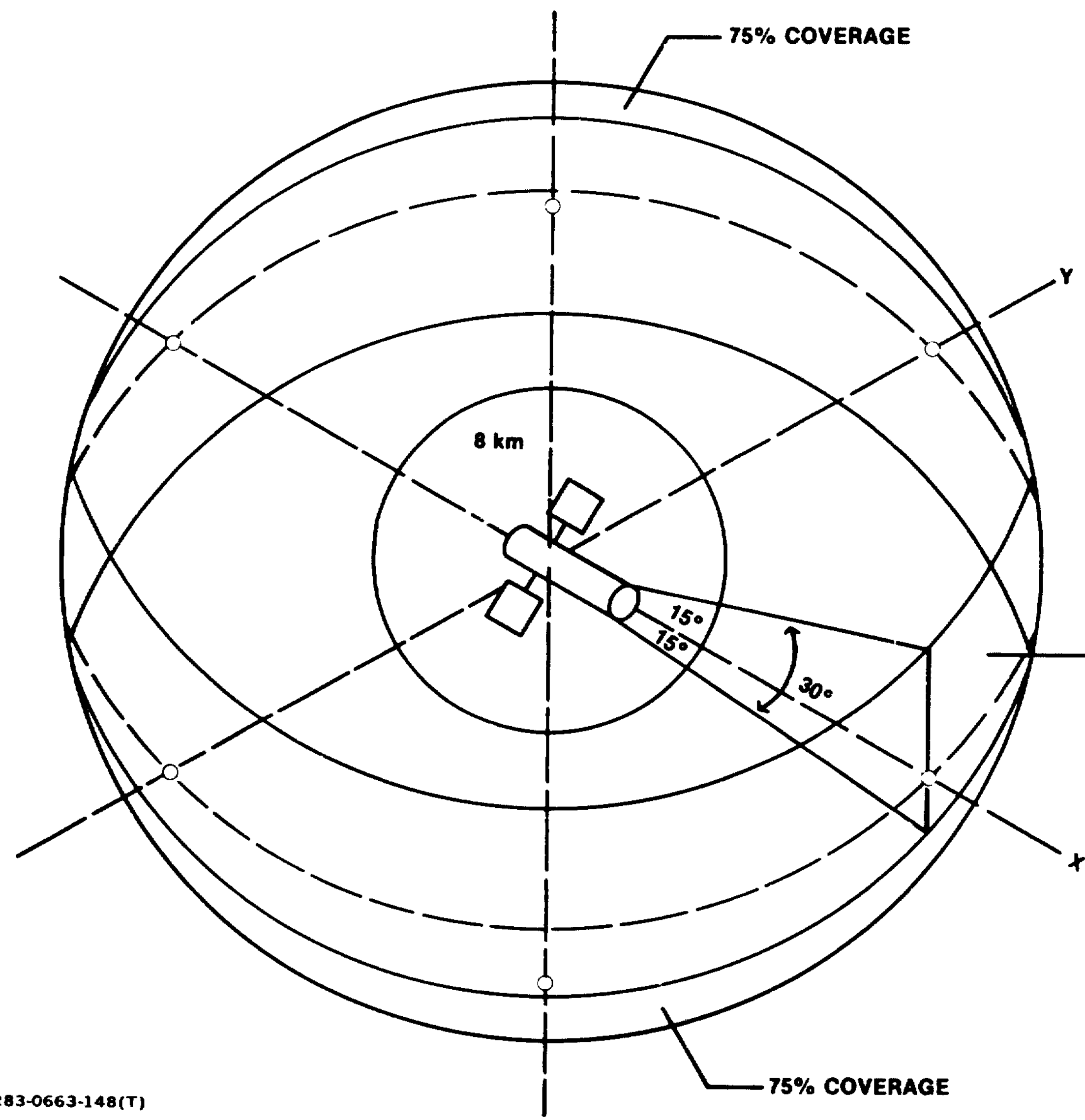

NOTES:
1. 100% COVERAGE WITHIN 8 km OF SPACE STATION.
2. 100% COVERAGE WITHIN ±15 DEGREES OF ORBITAL PLANE.
3. 75% OR GREATER COVERAGE WITHIN THE REMAINDER OF SPHERE.

*PERCENT COVERAGE REFERS TO UNOBSTRUCTED COVERAGE REGION.

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Figure 2.1 Required Field of View for Space Station Antenna Coverage

TABLE 2.2

NASA/GRUMMAN GENERAL REQUIREMENTS FOR THE INITIAL AND FULLY OPERATIONAL SPACE STATION RF COMMUNICATIONS AND TRACKING SUBSYSTEM

Preliminary On-board DMS Performance Requirements

Key Parameters		1900 (1)	2000 (Projected) (2)
Data Rates	Mission	50 - 120 x 10^6 bps	100 - 210 x 10^6 bps
	Operations	0.1 x 10^6 bps (3)	10^6 bps
Storage Capacity	Mission	1.0 x 10^{13} bits/day	2 x 10^{13} bits/day
	Operations	10^{10} bits/day	10^{11} bits/day
Processing Speed	Mission	10 - 40 Mop/s	50 - 100 Mcp/s
	Operations	4 Mop/s (Megaoperations/sec.)	8 Mop/s
Communications Rates		300 x 10^6 bps	500 x 10^6 bps

(1) Estimate based on preliminary analysis.

(2) Based on projected estimates of missions for 2000.

(3) 1500 TLM points monitored.

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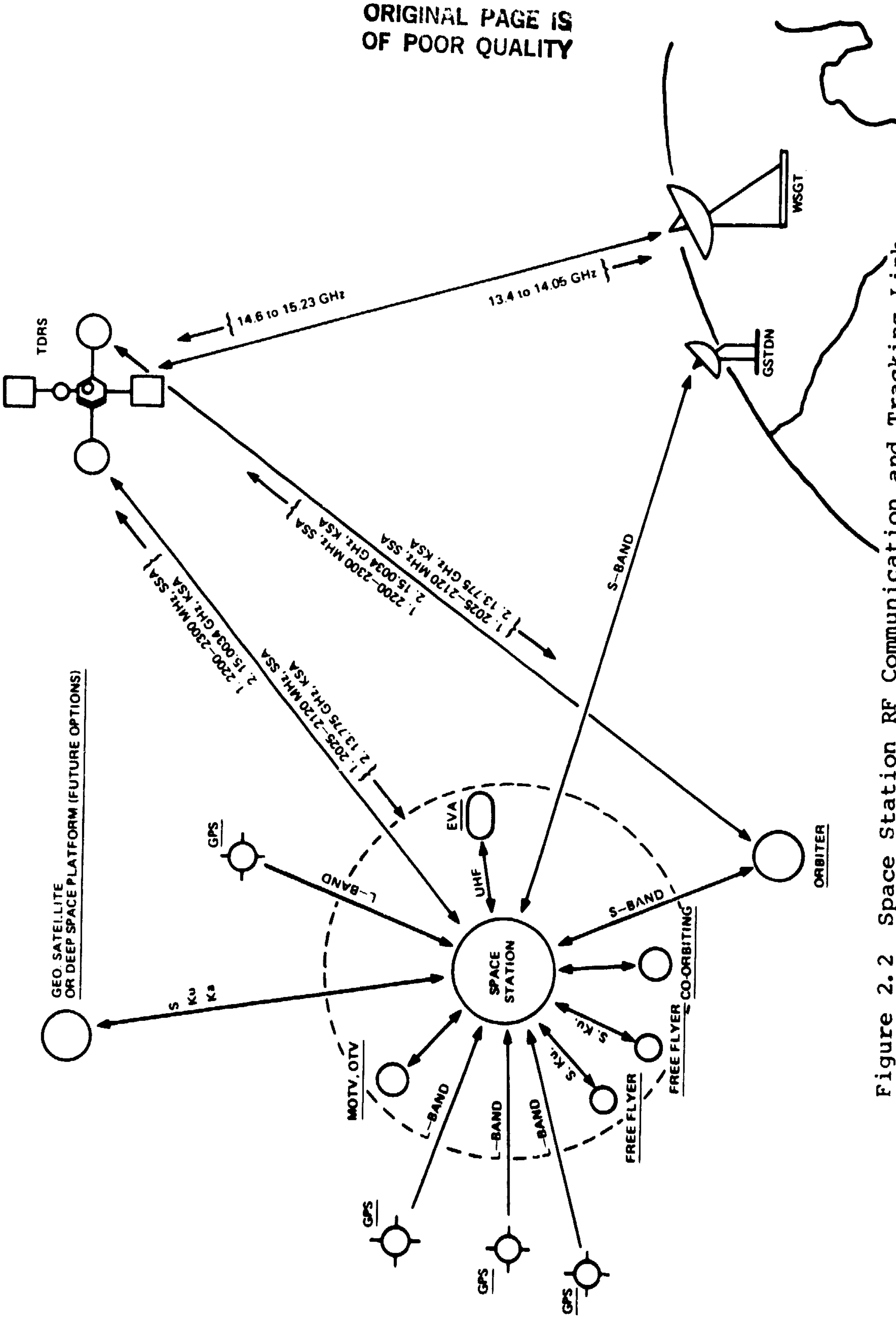

Figure 2.2 Space Station RF Communication and Tracking Link Functional Configuration and Frequency Plan

3. INITIAL SPACE STATION (1990) RF COMMUNICATIONS AND TRACKING SUBSYSTEM CHARACTERISTICS AND ATTRIBUTES

3.1 General Overview of Initial Space Station (ISS)

A simplified general overview of the Space Station is pictured in Figure 3.1 showing the major building blocks. The Space Station will be operated by a crew quartered in a habitat. The crew members will be performing various External Vehicular Activities (EVA). Operations will be essentially autonomous; however, two-way communications will be maintained constantly with the ground operations center either via a relay satellite (TDRS) or directly to ground (GSTDN back-up link). The RF communications system handles all external communications while Space Station (S/S) locations are obtained via the GPS navigation subsystem. The bulk of the data being transferred to ground consists of mission data (scientific, commercial, operations) collected and processed on board the S/S.

3.2 Approach and Guidelines

The overall approach to the study is described by the flow diagram of Figure 3.2. Preliminary guidelines for the design of the communications subsystem are proposed. These guidelines should be refined in an iterative process as various trade-offs are performed. These guidelines suitably modified as a result of future study efforts would eventually be included in a refined set of requirements for the ISS RF Communications and Tracking Subsystem (RFCT). Table 3.1 summarizes a preliminary set of guidelines.

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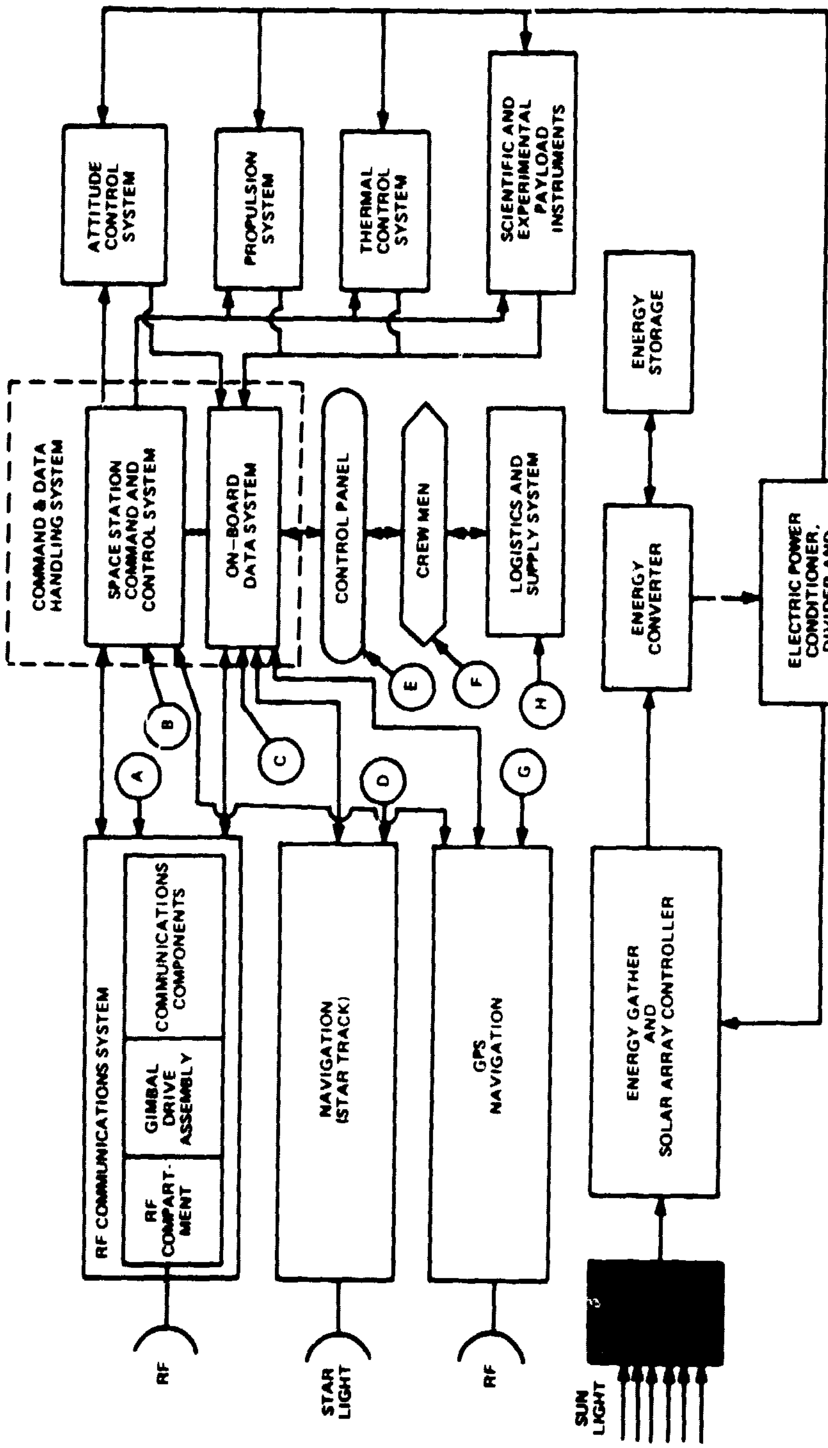


Figure 3.1 Overview of Initial Space Station Subsystems

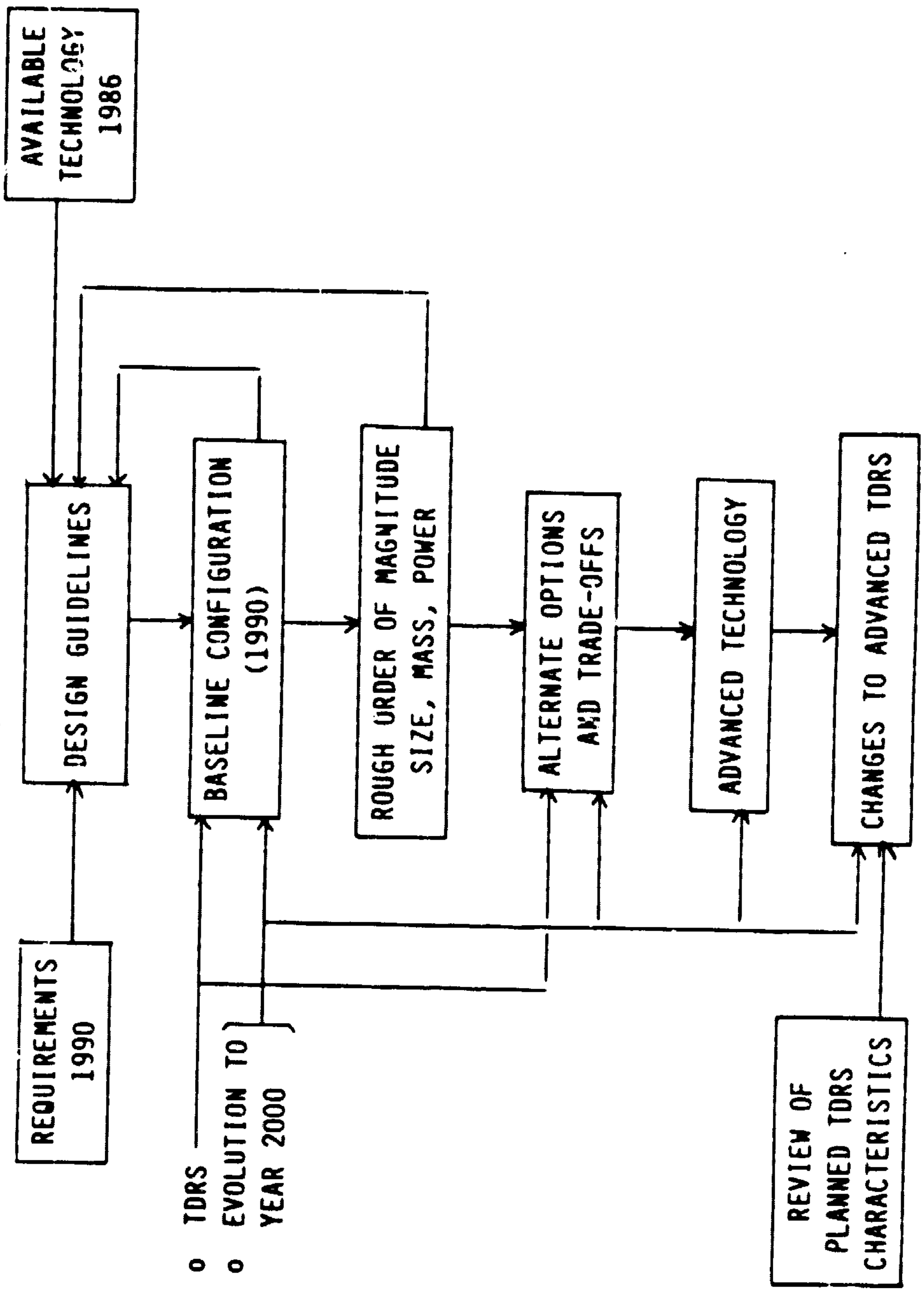


Figure 3.2 Initial Space Station RF C/T Architecture Study

TABLE 3.1 - CGC PROPOSED BASELINE INITIAL SYSTEM (1990)
PRELIMINARY GUIDELINES

1. Communications between S/S and ground via TDRS (direct S/S-to-ground link as back-up).
2. S/S - TDRS Link: Ku-band and S-band.
3. Exclusive use by the S/S of one of the two Ku-band beams of TDRS (KSA).
4. Highly reliable and survivable voice/data/command link for emergency communications operable during powered-down conditions.
5. All communications to be in digital format to the maximum extent possible (EVA voice could be analog initially). This provides for high operational flexibility and optimum use of TDRS capability.
6. Extensive use of solid-state amplifiers to the maximum extent possible.
7. Extensive applications of orbital and ephemeris data for (widebeam) antenna acquisitions and pointing with computer control program track.
8. Autotracking techniques to be used for narrow beam (Ku-band) antenna acquisitions and pointing.
9. Altitude and inclination of the initial space station = 230 n.mi./28.5°.

TABLE 3.1 - CGC PROPOSED BASELINE INITIAL SYSTEM (1990) PRELIMINARY GUIDELINES (cont.)

10. Advanced antenna concepts to be considered (e.g., Phased Arrays, Multiple-beam antennas)

11. Graceful evolution towards year 2000 Space Station.

3.3 Summary of General Requirements for the Baseline Initial RF Communications and Tracking Subsystem

The general requirements for the baseline initial RF Communications and Tracking Subsystem has been defined based on the NASA/Grumman Space Station requirements as described in Section 2. Table 3.2 summarizes such general requirements which appear to be somewhat more modest and less stringent than those for the fully operational Space Station in the year of 2000. The advanced technologies considered for the study of various RF Communications and Tracking Subsystem architectural options are those to be available in 1986.

3.4 Candidate Architecture and Attributes for the Baseline Initial Space Station RFCT

A block diagram of a typical RFCT subsystem architecture is shown in Figure 3.3. The interface with the Data Management Subsystem (DMS) is described in Figure 3.4.

The interface to the Data Management System (DMS) is via the Signal Interface Unit (SIU). Raw baseband stream data is supplied from/to the RF Communications and Tracking Subsystem. All data processing, such as, digitizing, multiplexing, formatting, and distributing, is the responsibility of the DMS. However, a portion of the SIU is part of the RF Communications and Tracking Subsystem. It will contain elements necessary to guarantee specified transmission performance.

Requirements to be defined in future studies should include the following:

- Forward Error Correction (FEC).
- PN modulator/demodulator, interleaver, doppler compensation, devices to protect against RFI from ground radar.

TABLE 3.2A - NASA/GRUMMAN PRELIMINARY REQUIREMENTS FOR THE BASELINE INITIAL SPACE STATION (BISS) RF COMMUNICATIONS AND TRACKING SUBSYSTEM

- Launch year: 1990
- Low-cost and low-risk
- Technology availability: 1986
- Scalability: Design should allow gradual evolution towards fully operational station without major redesign.
- Relay satellite: TDRS (up to about 1992)
  Advanced TDRS later
- Autonomy: Operation of communications subsystem by the Space Station crew will be essentially independent from real-time ground command (except for emergency and other situations).
- ISS to ground via TDRS: 300 Mbps (Ku-band)
  3.15 Mbps (S-band)
- Ground to ISS via TDRS:* Up to 24 Mbps (Ku-band)
  Up to 300 Kbps (S-band)
- Space Station Attitude: ±2°

Other requirements: Same as for the General Requirements listed in Tables 2.1 and 2.2

---

* Command Requirements, as well as other transmission requirements, from the ground to ISS via TDRSS have not been well established. The capabilities shown above are those presently available in TDRS

TABLE 3.2B - PRELIMINARY REQUIREMENTS FOR THE BASELINE INITIAL SPACE STATION COMMUNICATIONS LINKS

	Number of Vehicles to be served Simultaneously	Frequency Band
Relay Satellite	1	S, Ku
ORBITER	1	S
EVA	2	UHF
FREE-FLYER	1	S, Ku
GPS	1	L
Additional Back-up		
Direct link to GSTDN	1	S
TOTAL	7	

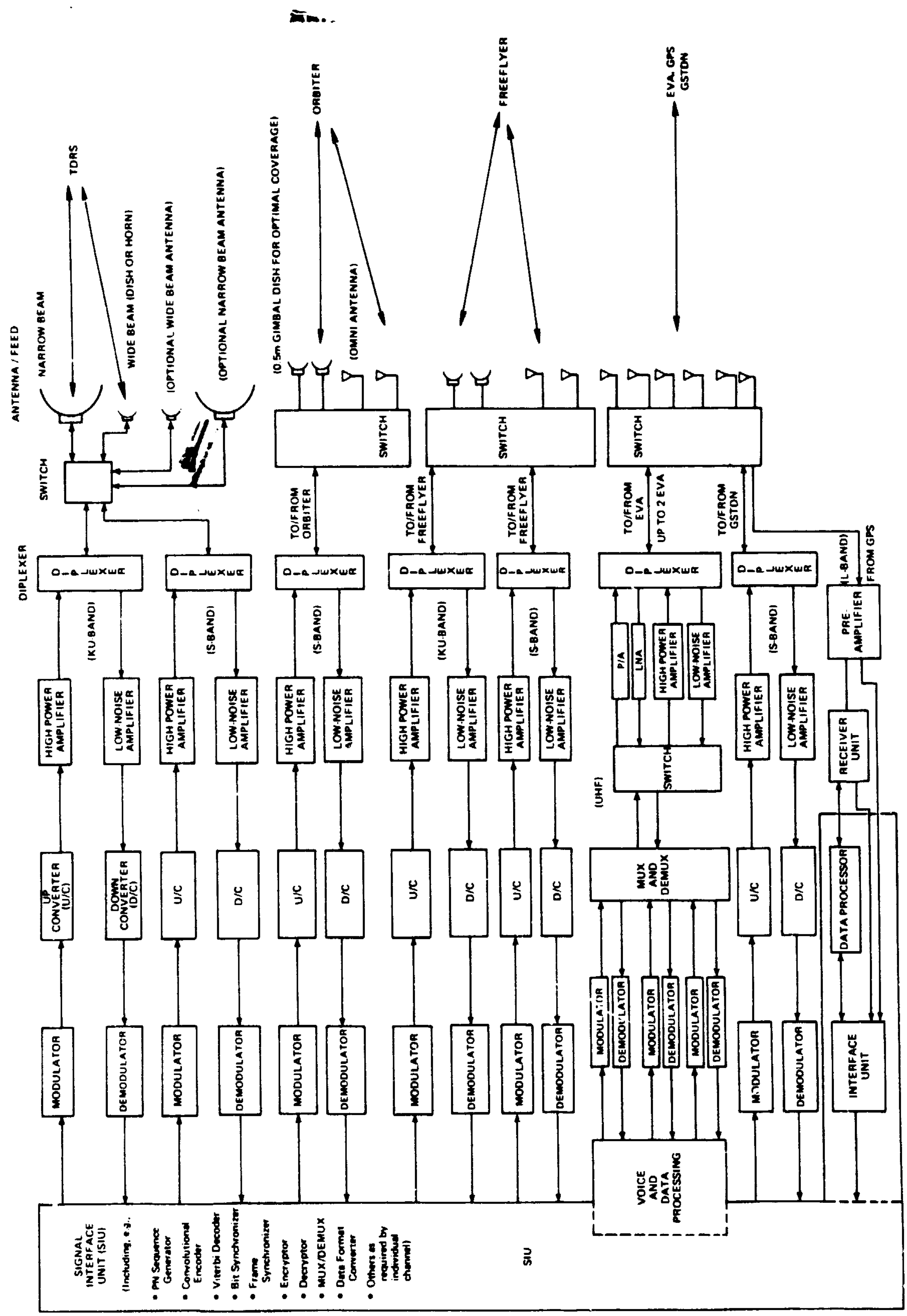


Figure 3.3 Functional Diagram of a Typical Communications/ Tracking Subsystem Architecture of Initial Space Station

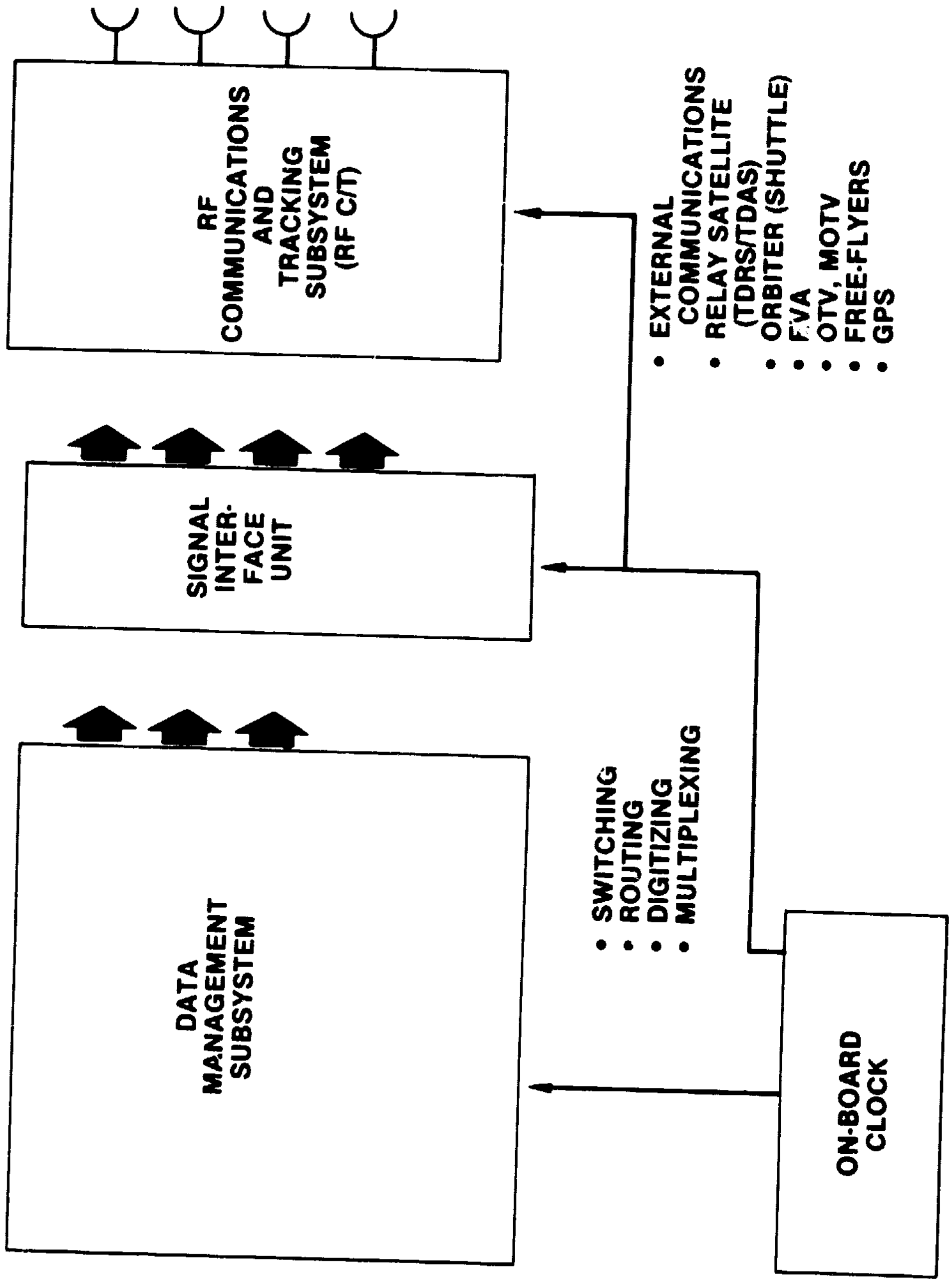


Figure 3.4 Interface with Data Management Subsystem

3.4.1 Antenna Coverage Requirements

The antenna coverage requirements are as follows:

For TDRS: The Space Station Communications Subsystem must acquire and lock on to TDRS [geosynchronous orbit (22,300 N.M.)] and vice versa. The relative location of spacecraft are obtained from ephemeris data and used in the computer-controlled antenna acquisition. Auto-track mode is used after Ku-band antenna acquisition.

For EVA: The wide angle coverage is required since crew (astronauts) could be located almost anywhere within a short distance (< 10 km) of the Space Station.

For Orbiter (space shuttle): Anywhere within sphere around Space Station (within 2000 km).

For Free-Flyer: A Free-Flyer is any payload detached from Orbiter or Space Station and is capable of independent operation. A Free-Flyer could be anywhere within a sphere around the Space Station (within 2000 km).

For Co-Orbiting Systems: A co-orbiting system is an integral element of the Space Station, but not physically connected to the S/S. Its relative location with respect to the S/S is essentially fixed. For communications purposes a co-orbiting system will be treated as a free-flyer. Further studies are required to refine these requirements.

GPS: The Global Positioning System is composed of a network of 24 navigation satellites in a 12-hour orbit (18,500 km altitude). The Space Station will receive L-band signals from any four well-separated GPS satellites to accurately predict its location.

The overall antenna coverage should cover most of the visible sky as shown in Figure 2.1 except the unavoidable blockage from the Space Station structure (such as, solar array).

3.4.2 Frequency Management

Figures 3.5 and 3.6 show some typical candidate frequency plans in the S-band and VHF bands. The Ku-band frequency will include those of TDRSS.

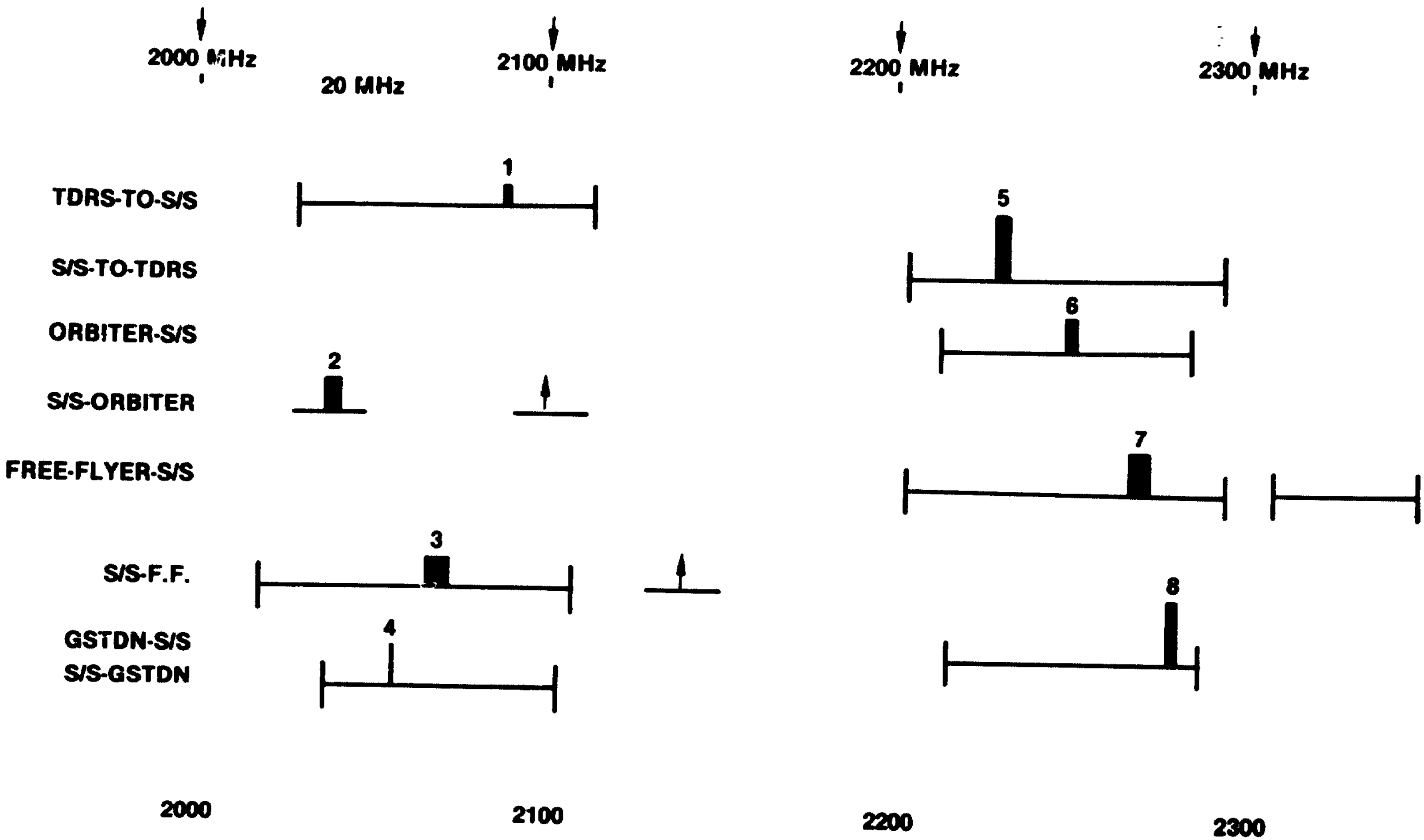
3.4.3 Antenna Requirements*

The following are some possible antenna requirements for architectural options. Some trade-offs are strongly recommended to evaluate the optimal size/type of candidate antenna architecture.

TDRS Link: Four dishes may be optimal for the TDRS link. Each set of two dishes could be used to establish communications with one of two TDRS satellites which happen to be in view of the Space Station. Each set is composed of a 0.5 m dish to facilitate acquisitions of the TDRS signal and of a 4 m dish for communications. Antenna pointing is achieved via gimbal drive mechanisms under computer control.

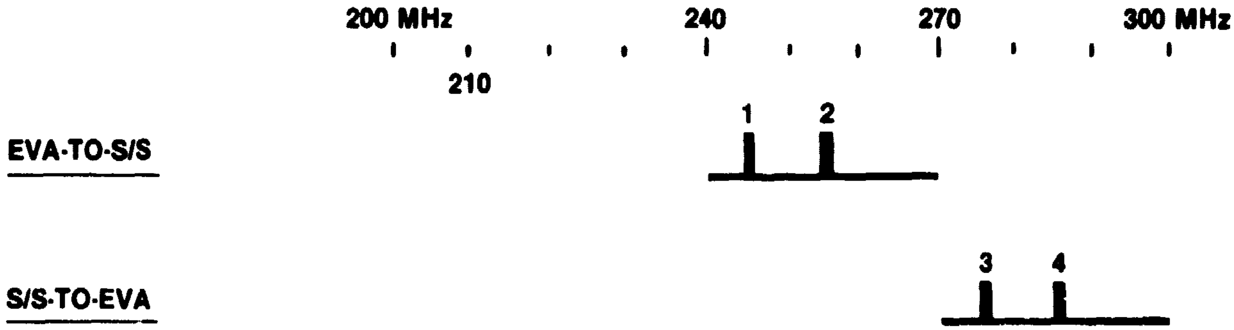
Orbiter Link: Two dishes (0.5 m) and two omni's could be used for long distances and short distances, respectively. One dish and one omni provide coverage above the Space Station while another set provides coverage below the Space Station.

*Antenna requirements need further trade-off studies among antenna size, power and achievable data rate. The 4 m and 0.5 m antennas are selected only for demonstration purposes in this study.



NOTE: SOLID LINES SHOW POSSIBLE FREQUENCY RANGE AVAILABLE CANDIDATE FREQUENCY ASSIGNMENTS ARE SHOWN AS #

Figure 3.5 S-Band Utilization (Initial Station)



NOTES: SOLID LINES SHOW FREQUENCY RANGE AVAILABLE
CANDIDATE ALLOCATION FOR 2 EVA'S ARE SHOWN AS #

Figure 3.6 UHF Utilization (Initial Station)

Free-Flyer Link: Two (0.5 m) antennas and two omni's could also be used. This antenna system will support both S-band and Ku-band communications.

Co-Orbiter Link: This link has not been considered explicitly in this study. Further study effort is required. The VHF band, V-band, or W-band could be used for this service.

EVA: Two omni antennas operating in the UHF band can be used similar to those of orbiter EVA's.

GSTDN: A horn would provide earth coverage at S-band.

GPS: A L-band omni antenna should provide the required coverage for the GPS receiver and processor assembly.

3.4.4 Mass and Power Estimates

Figure 3.7 shows components considered in the mass and power estimates of the RFCT. The R.O.M. mass and prime power estimates are:

Mass: 480 kg

Prime Power: 610 W

These estimates include the following features:

- 100% redundancy
- Hot standby

3.4.5 Trade-offs Among Alternative Architecture Configurations and Antenna Technology

The study has revealed that one of the critical requirements is the extensive coverage, acquisition and tracking capabilities needed to provide simultaneous communications with various vehicles. The total number of

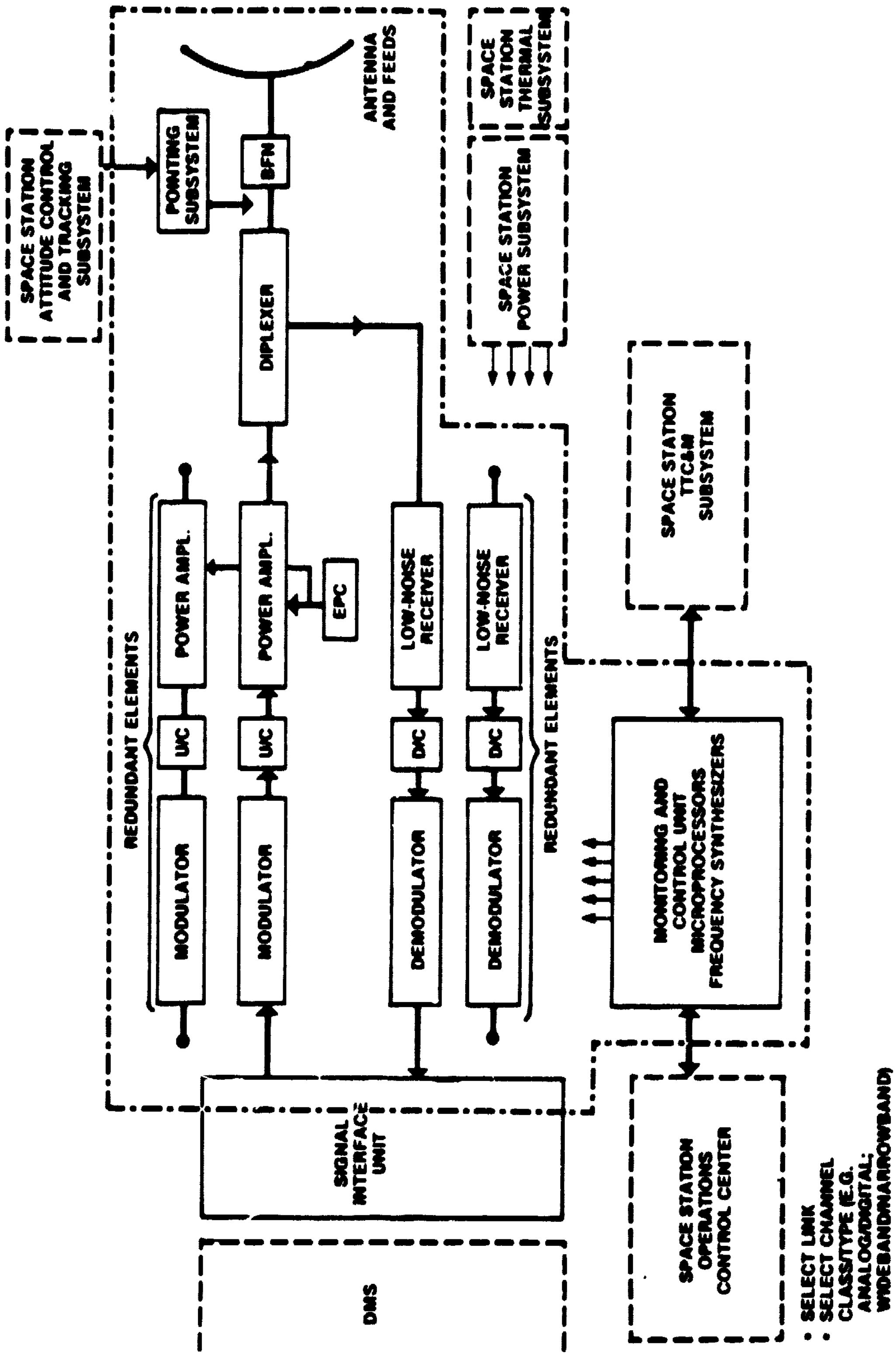


Figure 3.7 Functional Diagram of Communications and Tracking Subsystem (One Link Shown)

antenna dishes required in the baseline architecture amounts to two 4 m dishes, six 0.5 m dishes plus a number of omni and horn antennas (see Table 3.3).

Phased-array type antenna systems should be considered with the intent of combining antenna systems. The two main contenders are the following:

a) <u>Phased Arrays</u>

Beams are formed by feeding an array of radiators with adequately selected RF power levels and phase. Its advantages include the ability to form multibeams which can independently scan the coverage areas. The disadvantages are large size, mass and possibly bandwidth and gain limitations.

It is not known at this time whether one phased-array antenna can be used at both S-band and Ku-band. The major technological developments in this area have been done by the military. This issue needs further study.

b) <u>Phased-Array Feed System (Scanning Beam Antenna)</u>

This system uses a parabolic dish (off-set fed) with a phased-array feed system. The Bell System was developing such a scanning beam antenna system at Ku-band a few years ago. In this approach, the phased-array feed system, size and mass characteristics are more modest than for a pure phased-array system.

Another approach includes multifeed multibeam off-set fed antennas. In these systems, a large number of spot beams cover a large segment of the sky. Coverage is achieved by switching from one beam to the other.

TABLE 3.3

SUMMARY OF NUMBER OF ANTENNAS REQUIRED FOR THE BASELINE INITIAL SPACE STATION

Link to/from	4 meter* dishes	0.5 meter dishes	Omni	Earth Coverage Horn
TDRS	2	2		
ORBITER		2	2	
FREE FLYER		2	2	
EVA			2	
GSTDN				1
GPS			1	
Total	2	6	7	1

Note: 1. The two sets of dishes of the TDRS link are required to maintain continuity of communications when switching from one TDRS satellite to the second TDRS satellite.

One set could be eliminated to reduce mass and volume requirements at the expense of a perhaps more complex antenna pointing mechanism. Some loss of communications may have to be tolerated.

2. The actual number of antennas is preliminary and has to be further defined.

*3. Further trade-offs are required to reduce the 4 meter antenna size and increase power requirements.

Variations of this approach include the use of subreflectors. By moving the subreflector, a sector of the sky will be scanned. A parameter of importance is the off-axis scan loss which dictates the maximum coverage angle. It appears that this angle would be as low as $\pm$ 10° in systems with subreflectors. In others, the limitation appears to be $\pm$ 7 beamwidths. If the beamwidth of each spot is selected to be about 7°, one dish would be required for one 90° quadrangle leading to a total of eight dishes for complete sky coverage. Each dish would have about 1.5 m diameter. This solution does not appear promising but further investigation is needed. The trade-off of candidate antenna design alternatives for Space Station applications has been studied and summarized in the appendix. It appears that the gimballed dish or parabolic dish with phased-array feed MBA* system are good choices.

Table 3.4 shows candidate alternative architectures of the Space Station RF Communications and Tracking Subsystem. Future efforts are required to address the antenna system in more details.

In table 3.4 the antennas required for the link between the Space Station and TDRS are not shown. This set of antennas (which includes two 4 m gimballed dishes for communications and two 0.5 m gimballed dishes for acquisition) remains unchanged throughout the various options. In this link, only one beam (at each frequency) is required and communications

*MBA = Multibeam Antenna.

for a long time (no need for extensive acquisition and tracking capabilities). However, for the other links (orbiter, free-flyers) the antenna system must be sufficiently agile to:

- Provide simultaneous communications to various vehicles in the general vicinity of the space station
- Acquire and track vehicles anywhere in the whole sphere around the space station (extensive coverage required).

These requirements mean that the antenna system must either have a large number of single-beam dishes (one for each vehicle tracked) or provide a multibeam capability from each antenna. The second possibility leads naturally to a phased-array type of system.

Phased-array systems are divided into:

- Phased-Array Feed Systems - Parabolic dishes where the feed system is a Phased-Array
- Multiple-Access (MA) - Phased-array systems - No parabolic reflectors.

Presently, the first type appears to be the preferred one for the Space Station applications based on size, mass, and power considerations.

Option I is essentially cur baseline plus two additional 0.5 m antennas to provide better connectivity. A total of 6 dishes are required for links to orbiters, free-flyers... (plus two 4 m and two 0.5 m for the TDRS link). Option I will meet the communications and coverage requirements for

the Initial Station. It is the preferred solution because of hardware availability.

In the evolution to the year 2000, Space Station communications will have to be established simultaneously to a substantial number of vehicles. In this case, Option II, Phased-Array Feed Systems, is preferred. Technology development may be needed for operation in the space environment. Sector coverage is provided and a total of six units is needed to provide complete coverage.

Options III and IV involve Multiple-Access Phased Arrays and hybrid combinations of Phased-Array Feeds systems and gimballed-driven antennas.

3.5 Hardware Availability and Key Issues

Most of the required hardware is expected to be available in the 1986 time frame with the possible exception of sophisticated antenna systems. Key issues include:

- Antenna subsystems (phased-array versus gimbal dish).
- Frequency allocation and management.
- Interference control.
- Substantial use of TDRS capability.
- Space available for communications subsystem (in particular, antennas).
- Power, mass.
- Hardware availability.

3.6 Evolution for Year 2000

The number of simultaneously operating links will be substantially higher for the fully operational Space Station

TABLE 3.4

ASSESSMENT OF ALTERNATIVE ARCHITECTURES

(Antennas needed for communications with Orbiter, Free-Flyer, EVA)

	Number of Antennas Required	Comment/Remark
Option I (Dish with Gimbal Drive)	- 6 units of 0.5 m dish (for S and Ku) - 8 to 12 omni and horn antennas (for S, Ku, L, UHF) (Note: Additional antennas to improve coverage if needed)	- Relatively low cost - Relatively light weight - Good coverage - Technology proven
Option II (Sector coverage)	- 6 units of phased array feed MBA system (for S-band) - 2 units of phased array feed system (for Ku-band)1- Beam /Gimbal - 8 to 12 omni and horn antennas (for S, Ku, L, UHF)	- High cost - Heavy weight - Optimal coverage - Technology available - Development required for space operations
Option III (MA antenna system)	- 6 units of MA array antennas (for S-band) - 4 units of 0.5 m dish (for Ku) - 8 to 12 omni and horn antennas (for S, Ku, L, UHF)	- High cost - Heavy weight - Optimal coverage - Technology available - Space operational system under testing (TDRS)

Note: Add Four other dishes for TDRS links to all options (Two 4 m; Two 0.5 m)

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TABLE 3.4 (cont.)

ASSESSMENT OF ALTERNATIVE ARCHITECTURES

	Number of Antennas Required	Comment/Remark
Option IV (Gimbal and Sector) Coverage	- 2 units of phased array feed MBA system (for S-band) - 2 units of 0.5 m dish (for S and Ku) - 8 to 12 omni and horn antennas (for S, Ku, L, UHF)	- Medium cost - Medium weight - Good coverage - Technology available - Development required foı space operations

Note: Add four other dishes for TDRS links to all options (Two 4 m; Two 0.5 m)

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by the year 2000 (see Tables 2.1 and 3.1). This could lead to a possible frequency congestion problem together with heavy constraints on simultaneous vehicle tracking requirements.

Further analysis is required for this case. Present indications are that the solution to such a problem may be one or a combination of the following:

a) Some form of phased-array antenna system would be needed.

b) Frequency management and interference control would have to be carefully examined.

c) A high capacity dedicated return link (500 Mbps) would be needed for the advanced TDRS spacecraft. This could lead to the use of the W-band (50-60 GHz) or optical frequencies.

4. POTENTIAL TECHNOLOGY ADVANCES AND IMPACT

4.1 Identification of Potential Technology Advances

In forecasting technology advances and future system capabilities, a critical review was made of the ongoing communications research and development programs which are being supported by the NASA Headquarters program offices and field centers.

The communication technology initiatives being pursued by NASA were found to fall into three general categories:

1) Near-term technology (6 years) which supports on-going space programs.
2) Far-term technology (6 to 15 years) which enhances planned programs by providing technology options.
3) Speculative efforts (15 years) which enable future programs by providing new concepts.

In our review, the near-term technology is emphasized for the initial space station communications architecture, because of its degree of maturity and availability in the 1990 time-frame. The other two categories, far-term technology and speculative efforts, were considered to represent growth options which would enhance future system capabilities.

In selecting candidate communication systems technologies for use by the ISS, attention was given to identifying those technologies that would satisfy the needs of the space station and its user community. As shown in the Appendix, the candidate communications technologies were run through several filters to determine their compatibility with the space station and the user community needs. In this assessment such things as performance, availability, cost, mass, volume, and power, as well as mission need were used to further refine our selection for the initial system architecture. These criteria could not be used on the far-term and speculative technology efforts, since they lacked the required specification. Nevertheless, areas of promising advanced technology were identified.

4.2 Technology Forecast and Impact

The communication technologies identified in our technology forecast which could directly impact space station capabilities and system architecture are:

1) Antennas: Multibeam (MBA)
   - Phased array
   - Lenses

2) Feed horns and beam forming networks:
   - variable power divider
   - variable phase control
   - Monolithic microwave integrated circuits (MMIC)

3) Switches: For combining antenna systems
For beam switching (tracking purposes)

4) Low-noise amplifiers: GaAs FET

5) Power amplifiers: TWTAs, GaAs FETs

6) Modulation techniques: QPSK, OQPSK, BPSK, MSK, M-ARY PSK, Coded Phase Modulation

7) Interference control techniques

8) Doppler control technique

9) Processors: LSI, VLSI, on-board data processor, etc.

Table 4.1 presents the assessment of recent technology in the interested frequency bands for space station applications.

4.3 Potential Technology Advances

The potential technology advances that are the advances of technologies in the near-term (6 to 15 years) and speculative efforts (15 years) which represent areas of potential future enhanced capabilities. Typical examples of such technology advances are:

- Development of higher frequency bands (Ka-band or W-band).
- Development of optical communications links.
- Development of flexible modulation techniques which are characterized by bandwidth and power efficiency, robustness, and insensitivity to environmental interference and doppler shifts.

TABLE 4.1

FREQUENCY BANDS FOR SPACE STATION APPLICATIONS

Frequency	Advantages	Disadvantages
1. UHF/VHF (commercial) S-band	- Technology well established. - Low risk, low cost.	- Frequency congestion. - Potential RFI. - Limit to low rate users.
2. Ku-band	- Technology proven. - Relatively low cost, low risk. - High rate transmission.	- Additional development cost (such as power amplifier). - Potential frequency congestion in late 1990. - Acquisition problem due to the narrow beam and location uncertainty.
3. Ka-band	- Technology available. - Frequency and bandwidth highly available. - High degree of RFI immunity. - High rate transmission.	- Technology enabling and enhancement requiring development cost with some risk. - Acquisition problem due to narrow beam and location uncertainty. - Sharing with other commercial users.

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TABLE 4.1 (cont.)

FREQUENCY BANDS FOR SPACE STATION APPLICATIONS

Frequency	Advantages	Disadvantages
4. W-band (50-60 GHz)	- Very high rate transmission. - Frequency and bandwidth highly available. - Excellent RFI immunity.	- Technology R&D, and enabling development required. - Cost and risk are relatively high. - Acquisition and re-acquisition relatively difficult.
5. Optical Communications (Laser)	- Very high rate transmission. - Frequency and bandwidth highly available. - No RFI problem.	- Technology R&D and enabling development required. - Cost and risk are high. - Acquisition and re-acquisition relatively difficult.

- Development of high data rate modulators/demodulators.
- Development of antennas subsystems utilizing phased arrays, MMIC feeds, strip-line antenna feed arrays.
- Development of high power (200 W), long life, amplifiers.
- Development of low-noise uncooled receivers.

4.4 Alternate Antenna System Configurations

As part of our assessment of the space station communications architectures, a trade-off study was performed on candidate alternative antenna designs for space station application. In this trade-off study four different antenna configurations were evaluated. Results of this study are listed in Table 4.2.

4.5 Applicable Modulation Schemes for Space Station Considerations

In terms of modulation schemes, a variety of modulation techniques for digital data transmission has been examined, including QPSK, OQPSK, APK, MSK, M-ary PSK, etc., spectrum bandwidth/power efficiency, filtering sidelobe regeneration and detectability, for example, are examined. The choice of modulation schemes for space station application usually is determined by bandwidth limitations and power considerations. For minimum bandwidth, QPSK or OQPSK is better choice. The following modulation formats are used by TDRSS: QPSK, BPSK, and OQPSK.

TABLE 4.2

COMPARISON OF CANDIDATE ANTENNA DESIGN ALTERNATIVES FOR SPACE STATION APPLICATIONS

	Gimballed Parabolic Antenna	Gimballed Parabolic Dish With Scannable Subreflector	Phased Array Element Antenna (MBA)	Parabolic Dish With Phased Array Feed (MBA)
Gain	High	Medium to High	Low	Low to Medium
Pointing Accuracy	High	Medium	Low	Low
Data Rate Capability	High	Medium	Low	Low
Acq/Trk Power Requirement	High	Medium	Low	Low
Antenna Slewing Torque Noise	High	Medium	None (High if Gimballed)	None (High if Gimballed)
Complexity	Low	High	High	Medium
Reliability	High	Low	Low	Medium
Cost	Low	Medium to High	High	Medium
Preferred choice for Space Station Applications	•			•

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The modulation schemes of the initial space station should be TDRSS compatible. However, additional study efforts may be required to select the optimum modulation for the fully operational space station.

4.6 Multiple Access Techniques for Possible Space Station Applications

NASA traditionally develops and maintains a plan or schedule by assigning communications resources to users a few days (or hours) prior to real-time communications. This approach is actually the pre-assigned channel assignment approach. The scheduling and resource allocation are based on users' priority.

It appears that this approach is favorable to space station applications. However, other approaches, such as TDMA, CDMA, may be applicable in some conditions; further study efforts may be needed to select the optimal multiple access scheme for space station applications.

5. ADVANCED TDRS CAPABILITIES

5.1 Compatibility with Evolution to the Year 2000*

The Tracking and Data Acquisitions System (TDAS), which is the planned advanced TDRSS, is an outgrowth of TDRSS having greater data rate capacity (gigabits/second), increased capability and direct downlink from a TDAS relay satellite to user ground terminal. The planned TDAS satellite will possess new or enhanced capabilities such as on-board data processing, on-board intelligent switches, sophisticated antennas, reliable high power amplifier at S-band, Ku-band, Ka-band, W-band, and laser systems, etc.

The Ka-band, W-band and/or laser are candidate frequencies for cross link between two TDAS spacecraft. S-, Ku-, W-band and/or laser are considered for the inter-satellite link between TDAS and user (low orbiting) spacecraft. Ku-band and Ka-band are the most likely choices for the TDAS space-ground link. The TDAS spacecraft architecture, constellation, user RF interface and operational interface are to be defined with respect to frequency used, end-to-end communications connectivity, and user service and performance requirements.

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* The TDRSS evolution is based on the study results of Tracking and Data Acquisition System, by STI, Inc. and GSFC/NASA.

This evolution plan is based on the projected needs of the user community coupled with projected advances. Some planned improvements and enhancements of TDRSS for incorporation into TDAS in 1990 are highlighted in Table 5.1.

TABLE 5.1

PLANNED IMPROVEMENT/ENHANCEMENT OF TDRSS

- Improve the TDRS coverage capability for low orbiting users to 100% communication coverage.
- Increase TDRS return data rate capacity up to 1 GBPS (at least 500 Mbps as required by space station requirements).
- Consider laser or W-band for TDRS - Space Station high rate communications.
- Add more single access channels to each TDRS so as to adequately support medium and high rate users real-time communications.
- Improve TDRS/user satellite acquisition and auto-tracking capacity.
- Provide high data rate direct downlink (Ka-band) to a ground terminal dedicated to the space station.
- Introduce new technologies including: bandwidth efficient modulation techniques; data compression, advanced navigation and tracking; inter-satellite link; high power TWTAs (100-200 W); highly efficient IMPATT or FET amplifiers; multiple beam antennas system (reflector, microwave devices, phased array).

5.2 Additional Changes to TDRS to Accommodate the Space Station Needs

It is expected that there will be constraints associated with the planned TDRSS network operations. These constraints come from three sources:

1) Those defined in the TDRSS system requirements or specifications (see TDRSS Users Guide).

2) Those inherent to the NASA network operations, such as sun interference, user mutual interference and GRFI (Ground Radar Radio Frequency Interference).

3) Those coming from the TDRSS system design and implementation such as TDRSS ground station message buffer size and response time limitations, service real-time reconfiguration, KSA auto-track system detection and false lock, etc.

These TDRSS system constraints imposed on users such as the space station may become an operational problem if they yield any intolerable condition to the user communications operations. In order to mitigate such constraints, some desirable TDRSS improvement may be essential to the TDAS end users.

Table 5.2 lists typical examples of desirable TDRSS improvements as derived from the projected space station requirements in order to cope with such constraints.

TABLE 5.2

DESIRABLE TDRSS IMPROVEMENTS TO MEET SPACE STATION REQUIREMENTS

1) Develop a complete frequency plan so as to resolve any possible frequency congestion problem among TDRSS/TDAS, space station and other users.

2) Improve the TDRSS ground network, e.g., WSGT, NASCOM, NCC and POCC data and real-time message routing capability and capacity to improve the simultaneous operational efficiency and data throughput of the user end-to-end operations.

3) Increase the WSNGT/NASCOM capability to enable concurrent operations of high data rate/analog/TV channels, which may very likely occur during simultaneous operations of space station, orbiter, LANDSAT-4 and other users.

4) Augment TDRSS channel reliability (no channel loss during real-time communications or reconfigurations).

5) Enhance the TDRSS capability in detecting channel loss and in recovering channels.

6) Allocate a dedicated beam exclusively to the space station - TDRS/TDAS communications

Notes:
WSGT: White Sands Ground Terminal
NASCOM: NASA Communications (Network)
NCC: Network Control Center
POCC: Payload Operational Control Center
WSNGT: White Sands NASA Ground Terminal

6. CONCLUSIONS AND RECOMMENDATIONS

The preliminary study for the architectures and attributes of the RF Communications and Tracking Subsystem have yielded the following tentative conclusions and recommendations:

6.1 Initial Space Station (1990)

- External communications requirements are expected to be met using rather conventional communications hardware at Ku-band and S-band.
- R.O.M. mass and power estimates are expected to be about 500 kg to 800 kg and about 600 W to 1200 W for the initial RFCT subsystem.
- Further trade-off is possible to reduce antenna sizes at the expense of additional power requirements and achievable data rates. This could be done if it turns out that space needed to accommodate the size or number of antenna dishes is at a premium.
- Gimballed dishes plus omni/horn antennas are sufficient to meet the initial space station needs.
- The use of phased-array feed antenna systems or of phased-array systems should be investigated with a view of minimizing any antenna congestion problem.
- Simultaneous operation of various links appears possible for the initial space station.

Communications between co-orbiting elements of the space station could be realized using the VHF band in order to avoid a potential frequency congestion problem at Ku-band and S-band. Other candidate frequency bands are those assigned to inter-satellite links and also the W-band. Communications requirements for co-orbiting elements are to be further defined. Specific areas that should be further studied and investigated in the future include:

1) Antennas

Perform the needed trade-offs (performance, mass, power) for the Initial Space Station for the various proposed stations. Investigate any development needed for phased-array antenna systems and full phased-array systems. Obtain cost impact. This study will consider the impact of graceful evolution to the year 2000 operational Space Station.

The impact of using a separate co-orbiting Space Station module for all external communications should be investigated. This could lead to several potential advantages, namely:

- Minimum Structural obstruction
- No momentum transfer due to antenna motion to the other elements of the Space Station used for Mission operations
- Reduced internal interference.

The communications link requirements between this separate module and the other modules will have to be investigated.

2) Potential Interference Problems (and interference control techniques)

   a) Interference generated on-board the space station.

   b) Interference due to reuse of frequencies.

   c) Interference from other spacecraft.

   d) Interference from ground radars and other terrestrial sources.

3) Frequency Planning

   Frequency planning will need to be carefully investigated to minimize possible frequency congestion (evolutionary year 2000 Space Station).

4) TDRS Relay Capacity

   Potential scheduling conflicts among S/S and other TDRS users since close to about one-half of the TDRS relay capacity will be tied up for up to 10 hours per day to transmit mission data and other data to ground.

5) Other Relay Satellites

   Other International participants will need to communicate their individual data to their respective countries. Other Relay Satellites belonging to other countries may come in existence in the 1990s.

The additional communications equipment needed on-board the Space Station would need to be configured and investigated.

6) Frequency Congestion

Frequency congestion alleviation by providing the Free-Flyer with a direct TDRSS link capability in addition to the space station link. The Free-Flyer to space station link would be a bent pipe-type to TDRSS and there to ground. The Free-Flyer direct TDRSS link would also apply during those times the space station to TDRSS link is not active.

7) Command Control

At least 100% redundancy will be required. Further study should be made to the real-time DMS-communications command control interface. This would include the following:

- Antenna and discrete subsystem activation-operation
- Performance monitoring
- Common element transfer switching
- Antenna and/or subsystem cross-over switching
- Associated impacts of the above to redundancy requirements

6.2 Evolution of Initial Space Station to the Year-2000

- More sophisticated antennas (e.g., phased-arrays) are expected to be required to handle simultaneous communications to various vehicles.
- Frequency allocations and potential interference problems require careful investigation.
- Potential frequency congestion problems could probably be alleviated by traffic scheduling (demand-assignment).
- Additional relay capacity is needed. This should be accommodated by the second-generation TDRS (TDAS) using Ka-band, W-band or optical communications. Development of TDAS should be carefully studied and monitored. As an example, TDAS could have a beam dedicated exclusively to the space station.
- Impact of advanced technologies should be further investigated.
- Mass and power budgets require further study.